BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B69 03082

SUBJECT: Trip Report - Discussion of Design and Fabrication Techniques for 1 1/2 Stage Integrated Launch Vehicle Drop Tank - Case 105-3

DATE: March 24, 1969

FROM: A. S. Kiersarsky

ABSTRACT

One of the studies currently being conducted for low cost earth to orbit and return transportation is the Lockheed Missile and Space Division "Space Shuttle" concept, which was previously designated "Starclipper". This is a 1 1/2 stage system consisting of two major components, a reusable spacecraft and a drop tank containing the boost propellant. The drop tank uses both pressure stabilized and statically stable structure. The propellant tanks are designed as ring stabilized monocoque structure without longitudinal stiffening, whereas the nose cone, intertank structure and thrust structure use integrally stiffened structure.

The drop tank, being expendable, imposes one of the major recurring cost items to the overall operation of the system and is presently quoted by Lockheed to cost $34 per pound at the 200th production unit. Lockheed has arrived at this cost by use of aircraft design techniques along with production fabrication methods. This has led to the use of tank skin in the as rolled condition, deletion of machining and chem-milling to provide lands for fusion welding, maximum use of resistance welding for tank joints, and use of automatic fabrication techniques.

The resistance weld technique was selected as the primary method of fabrication. This method is used both for joining and pressure sealing of the propellant tanks. Also, a more advanced method of fabrication known as the "Glue Weld" process is being studied. This process employs the use of an aluminum filled epoxy and the resistance weld technique. "Glue Welding" was initiated by the Russians and has been used by them for fabrication of missile and aircraft structures.

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MEMORANDUM FOR FILE

The writer visited the Lockheed Missile and Space Division, Sunnyvale, California on February 13, 1969 for the purpose of discussing their design approach and fabrication methods used for the drop tanks of their stage and one-half launch system. Participating Lockheed personnel were G. Alexander, J. Milton, P. Planck, F. Guard, W. Crane, M. Vaughan, R. Hammitt, K. Urbach, and F. Sullivan.

Introduction

Lockheed is currently engaged in the study of a low cost earth to orbit and return transportation concept they call the "Space Shuttle" (figure 1). It was previously designnated the "Star Clipper." This is a 1 1/2 stage integral launch system consisting of two major elements, a reusable spacecraft incorporating the boost engines, some propellant tankage and other system equipment and an expendable drop tank containing most of the boost propellants.

Discussion in this memo will concentrate on the drop tank which is one of the major recurring costs items in the overall operation of the system. Lockheed is presently quoting a cost of $34 per pound at the 200th production unit. There has been no firm hardware data other than small test specimens upon which to substantiate this cost.

For purposes of cost optimization, the drop tank component weight was considered as a design variable permitting a tradeoff in weight increase to achieve decreased costs.

In the following paragraphs some of Lockheeds' proposed design and fabrication methods are discussed.

(NASA-CR-103979) DISCUSSION OF DESIGN AND FABRICATION TECHNIQUES FOR 1 AND 1/2 STAGE INTEGRATED LAUNCH VEHICLE DROP TANK TRIP REPORT (Bellcomm, Inc.) 20 p

N79-72113

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Design and Fabrication Selection

The propellant tank design is dictated by a combination of internal pressure considerations and external loads. The tank internal design pressure was sufficiently high to allow a monocoque structure throughout the tanks except at concentrated load points such as in the area of the aft thrust structure. Therefore, the propellant tank construction could be primarily ring stabilized monocoque type without longitudinal stiffening. For the nose cone, the intertank structure, and the aft thrust structure part of the LH_2 tank, integrally stiffened structure was used.

In general, the drop tank design features

- considerable use of material in the as rolled condition,
- a minimal number of components for the large cylindrical sections,
- commonality of parts and forming dies for the dome sections,
- minimal use of fusion welding (maximum use of resistance welding),
- considerable use of uniform gauge components,
- almost complete elimination of machining and chem-milling except for small integrally stiffened sections,
- use of low cost material,
- maximum use of practical fabrication methods, and
- use of automatic fabrication and inspection techniques.

Configuration

The drop tank (figure 2) consists of five (5) primary assemblies comprising a nose section, a Lox tank which is made up of two mirror reflected sections spliced along the centerline, and two LH_2 tanks each joined to an interstage structure that is part of the lox tank. When assembled, the drop tank forms an inverted "V" within which is supported the reusable spacecraft.

The structure breakdown into these five sections (figure 3) was made for the purpose of handling and transportation from the manufacturing facility to the assembly and launch site. The components were required to be transportable by the Super Guppy Aircraft. Rail transport of the drop tank was also a major consideration in the structure breakdown.

Material

The primary material used in the drop tank is 2219-T87 aluminum. This material has excellent forming qualities along with good weldability and is economically competitive with other possible materials. Table 1 presents a comprehensive matrix of materials which have been used or are presently being studied as candidate materials for cryogenic tankage. As shown in Table 1, each was examined for forming, machining, and welding characteristics as well as the cost per pound. Lockheed's selection of the 2219 aluminum is consistent with their approach to low cost tankage.

Fabrication Techniques

Along with the monocoque design, the selected fabrication method which best suited this design was the resistance weld technique both for joint splices as well as for pressure sealing of the tankage. As an alternate tank fabrication method Lockheed is extensively studying the use of a process which Lockheed calls "Glue Weld". This process, which is relatively new, employs the use of an aluminum filled epoxy and spot-welding.

The resistance weld approach provided one of the major impacts on tank cost using the monocoque design where skin panel gauges vary only as dictated by the structural design requirements. Also, the selection of this fabrication method provided the basic tooling for tankage size control since the inside surface of the roll formed skins are joined to precise diameter controlled ring members. Here, the increase or decrease of the skin gauges required in different sections of the tank would have no effect on tooling since its growth would always be outward.

One of the basic outgrowths of the resistance weld method was a considerable reduction of both machining and chem-milling. This resulted from being able to use the skin panels in the required gauge. If the fusion weld method had been selected the gauge would be dependent on the weld joint and repair allowable stresses. A typical joint for the resistance weld is shown in figure 4 and for the glue weld in figure 5.

In the alternate process, "glue welding", jointing is accomplished through application of a high strength adhesive to the joint interface and spotwelding through the lapped metal joint. The adhesive in the precured condition is then cured at 250°F for one hour. The pressure generally used with this type of bonded joint is produced by the spotwelding procedure.

The adhesive is procured from the Minnesota Mining Co. (3M) and is designated as 3M-2214 epoxy. The adhesive is a matrix of high strength epoxy with an aluminum filler. The Joints and Splices Group at Wright Field, having been apprised of the method by the Foreign Technology Branch at the same location, referred this process to Lockheed. This process was originated by the Russians and has been applied in their missile and aircraft programs.

For anyone who has not been previously associated with the resistance weld method of joining structure, the placing of any contaminant between the surfaces to be joined was considered detrimental to the design efficiency of the joint. In other words, it was just not done. Therefore the glue weld method appears to be a step forward in the state of the art of joining. Lockheed indicated that the adhesive was not compatible with lox, but showed no adverse effects when used with LH_2.

Test Program

The use of resistance welding is not a new fabrication method but has had limited application to space program hardware. The one program using this technique of fabrication is the Atlas. Structural aspects of this method are well tested and documented.

The glue weld technique on the other hand is new to the family of fabrication methods and will require extensive testing. Lockheed has been and is presently conducting a test program of this process which includes

- basic tensile coupon testing,

- pillow specimen testing,
- fabricating a 20 inch diameter subscale test article, and
- fabricating a 13 foot diameter tank.

Tensile Specimen testing has been performed by the Manufacturing Research Group at Lockheed to assess the structural properties of this method. Testing to date has been made on two joint configurations, both using glue weld the difference being the amount of overlap. One set of specimens is overlapped by one inch while the other was overlapped only a half-inch. These tests showed excellent results. For each type of joint, 25 specimens were tested. A dispersion of 4 1/2% was noted in the failure data. The failures in both methods of testing occurred in the parent material.

Two pillow test specimens were fabricated. One uses the resistance weld method and the other uses the glue weld. As shown in figure 6 the failure of both occurred external to the joining area.

A subscale tank (figure 7) 20 inches in diameter and approximately 3 feet long was fabricated using the glue weld method. Initially this specimen was to be closed by hemispherical heads at both ends but to facilititate fabrication, a flat membrane closed in one end. The tested tank failed along the flat membrane joint whereas the rest of the tank showed no irregularities or evidence of failure.

Lockheed plans on constructing a full scale test specimen 13 feet in diameter using the glue weld method of joining and sealing.

Cost

Lockheed predicts a cost of $34 per pound at the 200th production unit (figure 8). They have noted that the production rate is the critical factor. Considering this low cost, one would then ask just what may be the cost of the first production unit. The predicted cost of the first unit along with a comparison of other systems is shown in figure 9 and is estimated to be $125 per pound. These figures are only estimates with little actual experience to substantiate them. Hopefully, the large scale test tank will generate some worthwhile data.

Additional Note

For anyone's examination the writer has in his possession a sample of the Lockheed LI-15 heat shield material.

A. S. Kiersarsky

1013-ASK-kle

Attachments

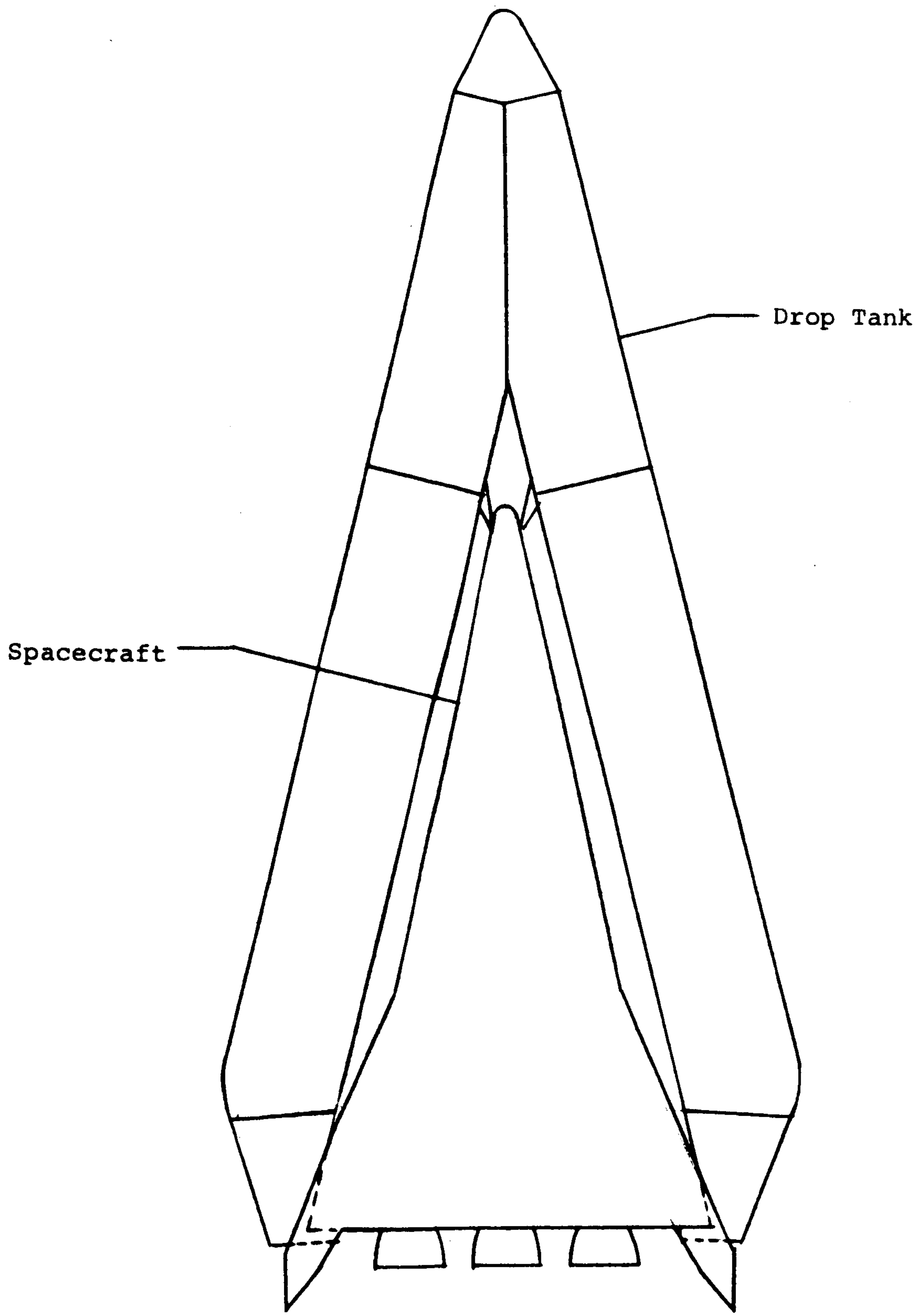
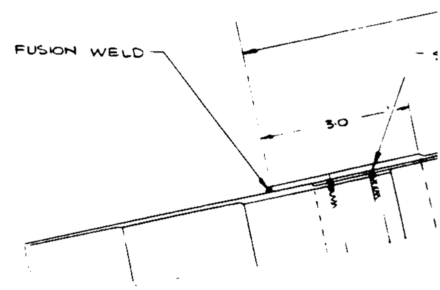
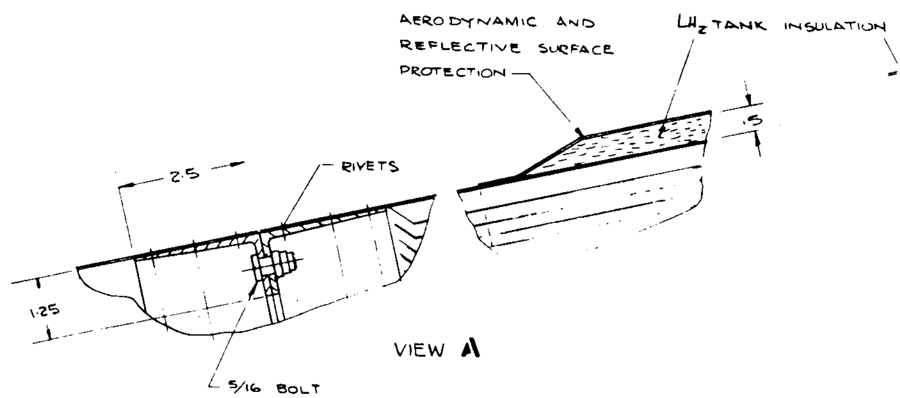
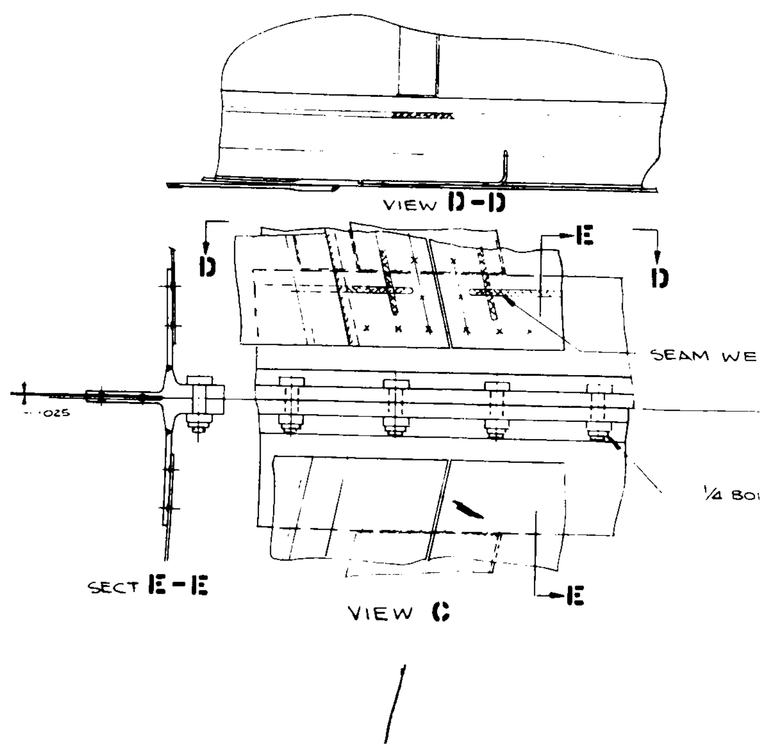


FIGURE 1 - LOCKHEED "SPACE SHUTTLE"





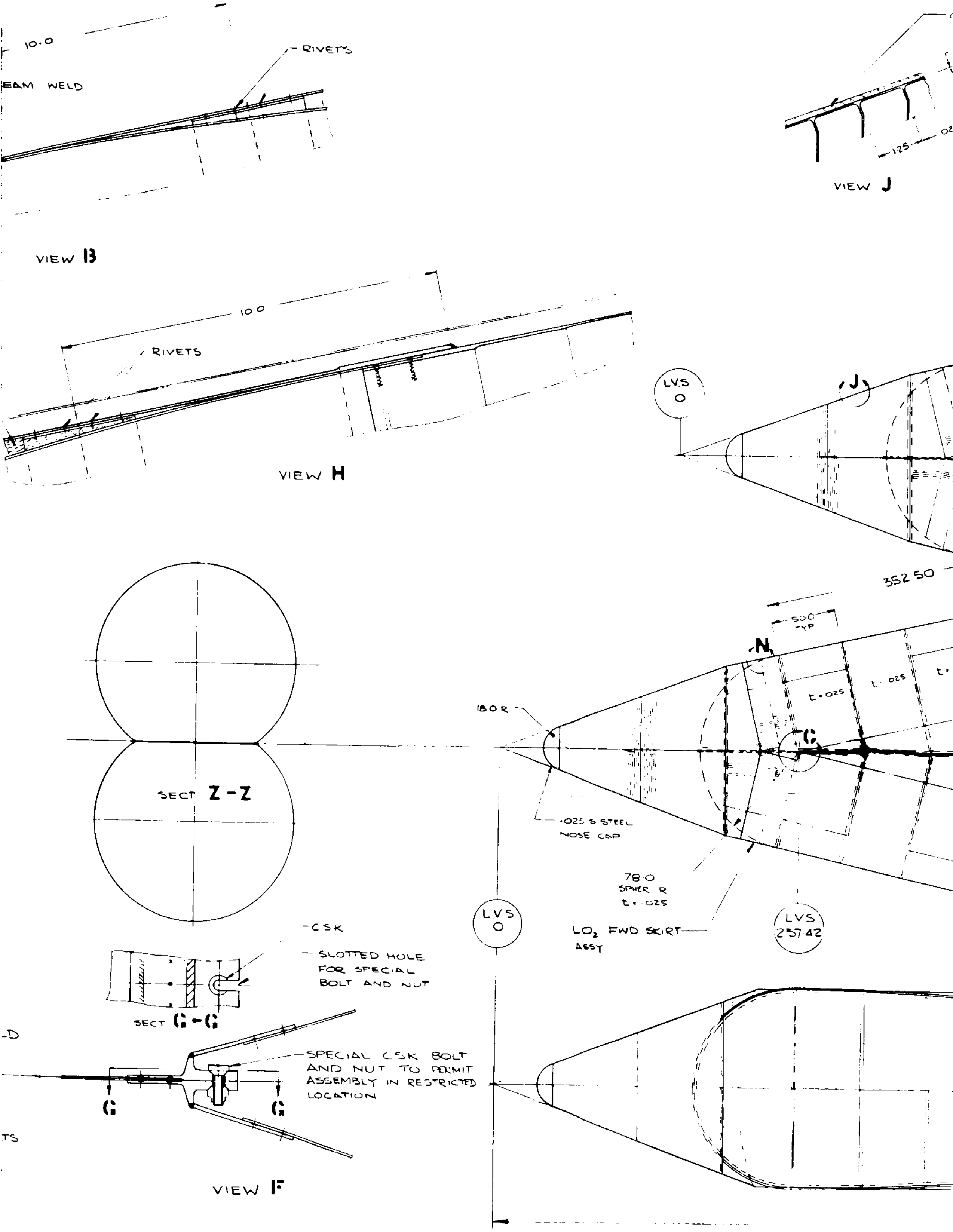
VIEW A



VIEW D-D

SECT E-E

VIEW C


10.0
RIVETS
EAM WELD
VIEW B
VIEW J
.125
10.0
RIVETS
VIEW H
LVS
0
J
352.50
.500
TYP
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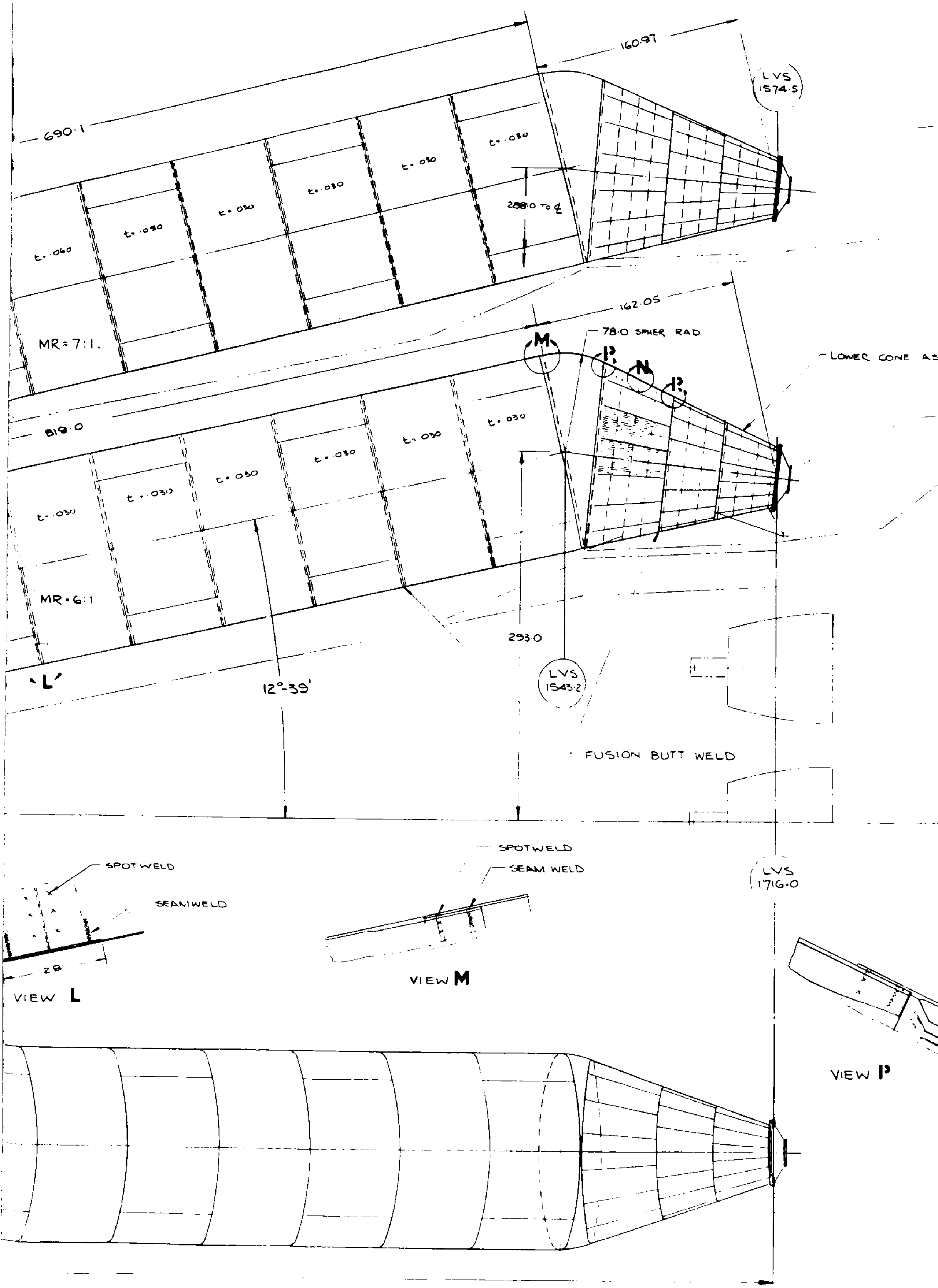
t=.025
t=.025
180 R
C
.025 S STEEL
NOSE CAP
78.0
SPHER R
t=.025
LO2 FWD SKIRT
ASSY
LVS
0
LVS
257.42
SECT Z-Z
CSK
SLOTTED HOLE
FOR SPECIAL
BOLT AND NUT
SECT G-G
D
SPECIAL CSK BOLT
AND NUT TO PERMIT
ASSEMBLY IN RESTRICTED
LOCATION
G
G
TS
VIEW F

ORK INSULATION
SEE TABLES 1 & 2
L
RING SPACING
1.25
VIEW N
176.6
30.0
69.0 (TYP)
t = .065
t = .070
t = .075
LVS 238.5
332.0
30.0
13°-54'37"
TANK INTERCONNECT ASSY
LO2 AFT SKIRT ASSY
166.5
25.0
75.0 (TYP)
30.0
Z
t = .050
t = .060
t = .065
t = .070
t = .075
t = .050
t = .045
t = .040
t = .035
156.0 DIA
LH2 FWD SKIRT ASSY
78.0 SPHER RAD
t = .025
METALLIC SEAL RING, CONOSEAL APEX OR EQUIV
1.25
30.0 DIA MANHOLE
VIEW K
143 FT 0 IN



690·1
160·97
LVS 1574·5
t·060
t·030
t·030
t·030
t·030
t·030
288·0 TO ℄
MR = 7:1
162·05
78·0 SPHER RAD
M
P
N
P
LOWER CONE AS
819·0
t·030
t·030
t·030
t·030
t·030
t·030
MR·6:1
293·0
LVS 1543·2
'L'
12°-39'
FUSION BUTT WELD
LVS 1716·0
SPOTWELD
SEAMWELD
28
VIEW L
SPOTWELD
SEAM WELD
VIEW M
VIEW P

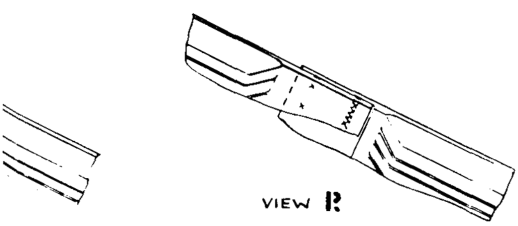
H

	L	b_w	t_R	t_s	t_w
LO_2 FWD SKIRT ASSY					
LO_2 AFT SKIRT ASSY	15.0	.36	.353	.03	.036
TANK INTERCONNECT ASSY	15.89	.42	.429	.031	.047
LH_2 FWD SKIRT ASSY	15.0	.422	.429	.031	.047
LOWER CONE ASSY	13.5	.435	.433	.034	.060

TABLE 2 MR = 7:1

	L	b_w	t_R	t_s	t_w
LO_2 FWD SKIRT ASSY					
LO_2 AFT SKIRT ASSY	15.0	.36	.353	.03	.036
TANK INTERCONNECT ASSY	15.89	.42	.429	.031	.047
LH_2 FWD SKIRT ASSY	15.0	.422	.429	.031	.047
LOWER CONE ASSY	13.5	.435	.433	.034	.060

TABLE 1 MR = 6:1



VIEW R

Figure 2 - Space Shuttle Drop-Tank General Arrangement

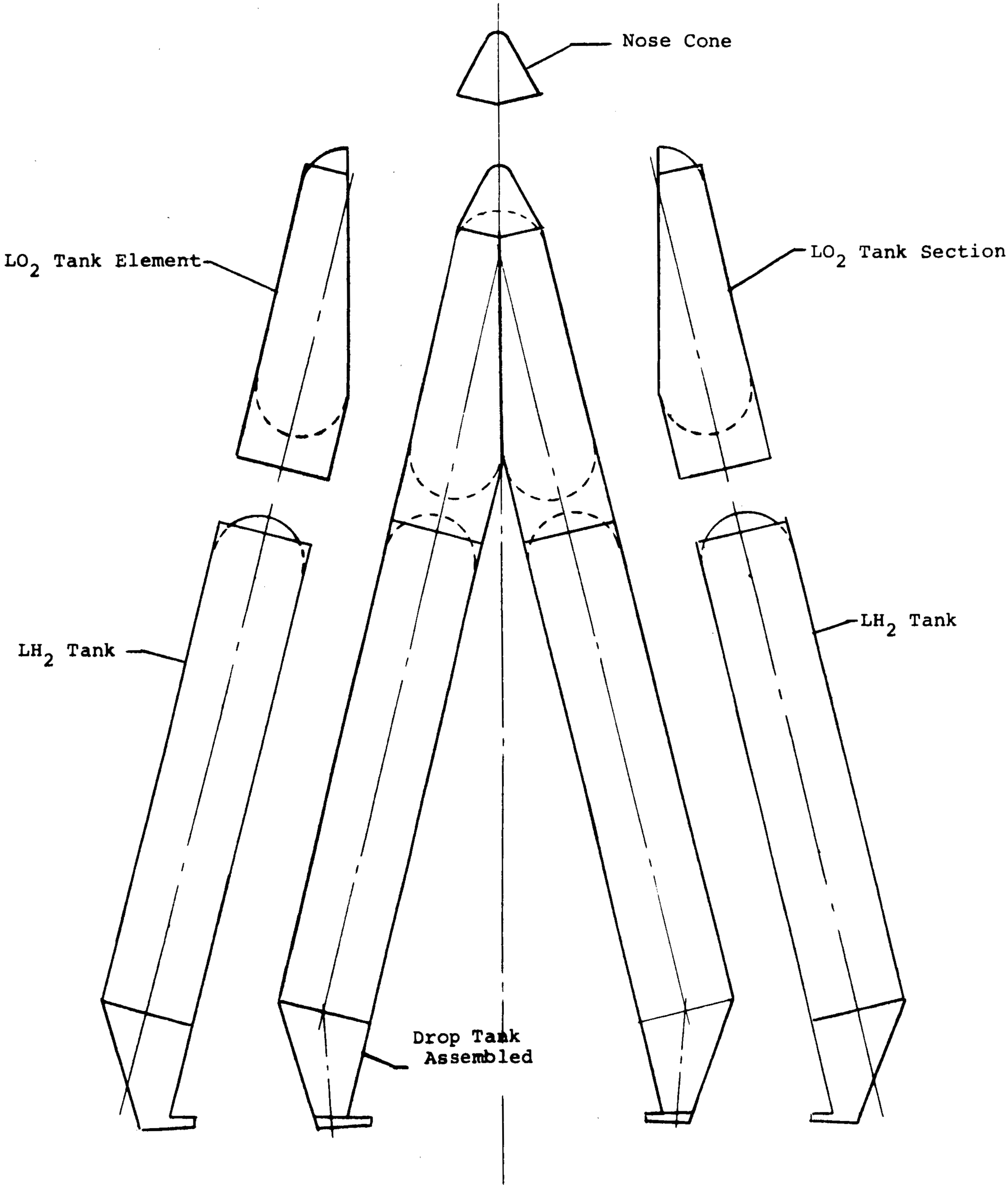


FIGURE 3 - DROP TANK STRUCTURAL ELEMENTS

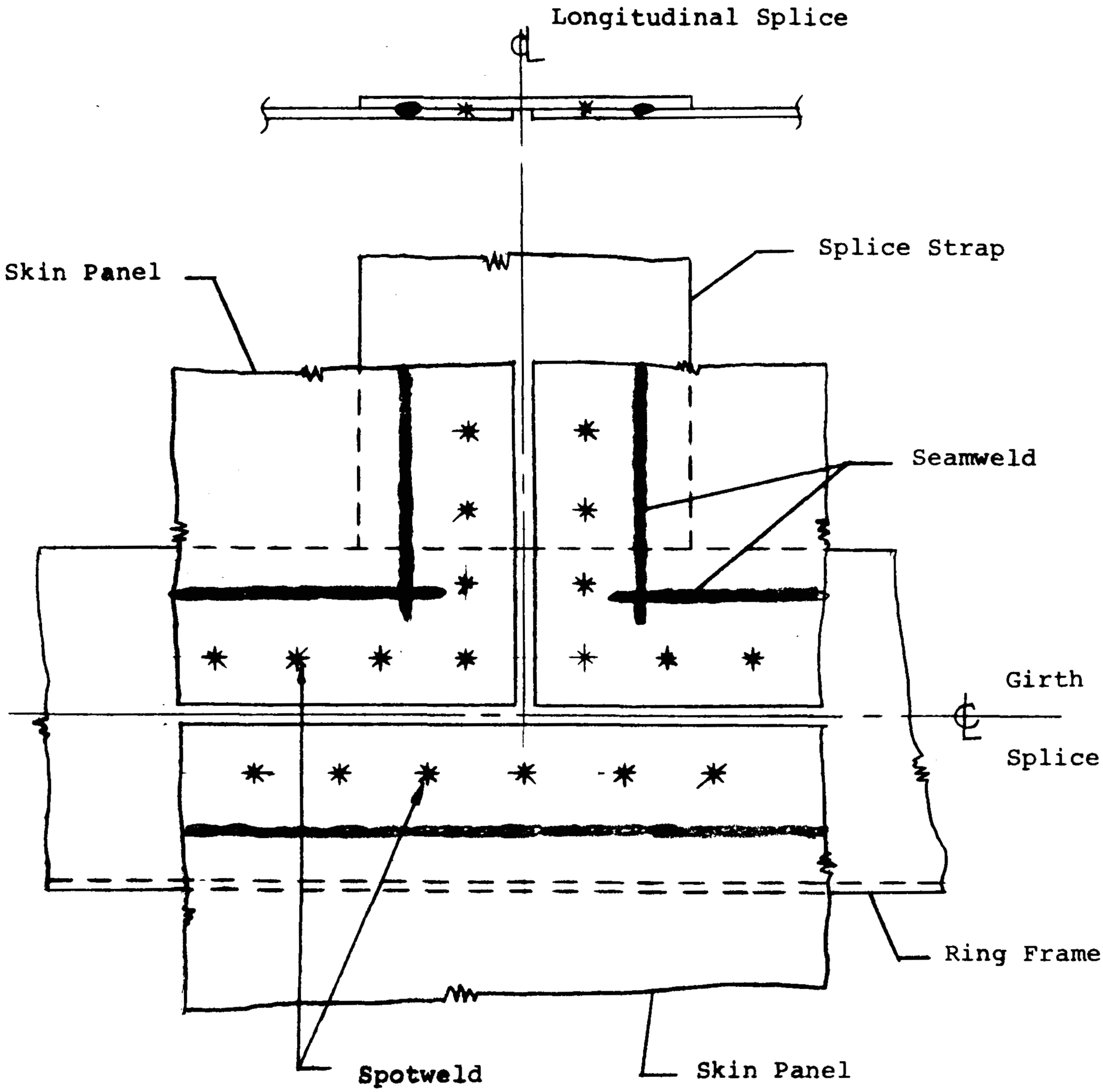


FIGURE 4 - TYPICAL RESISTANCE WELD JOINT

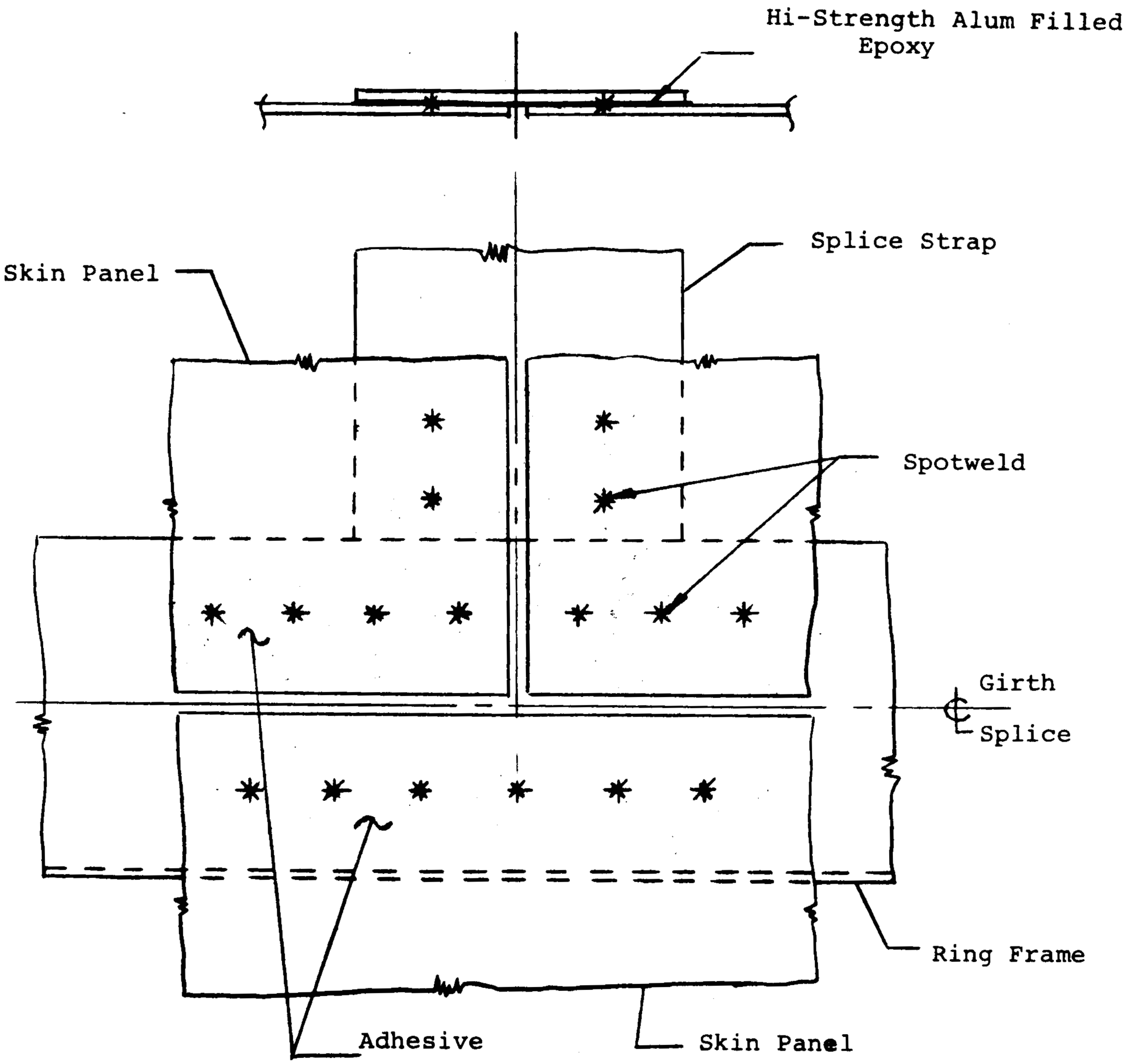
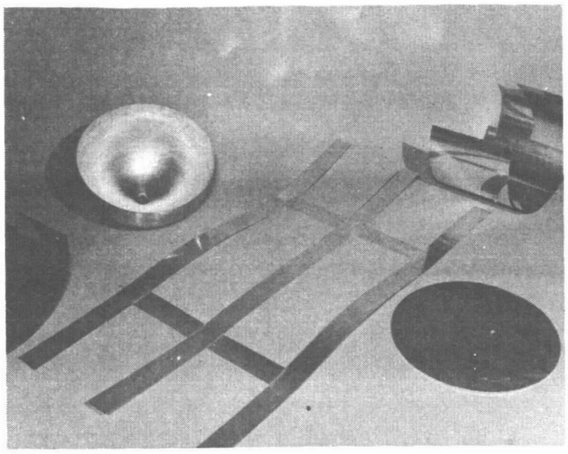
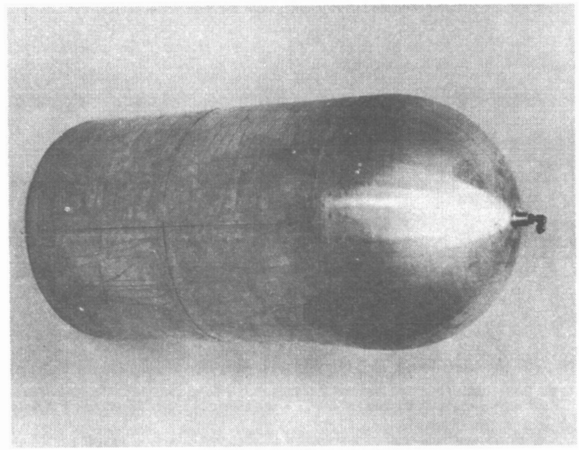


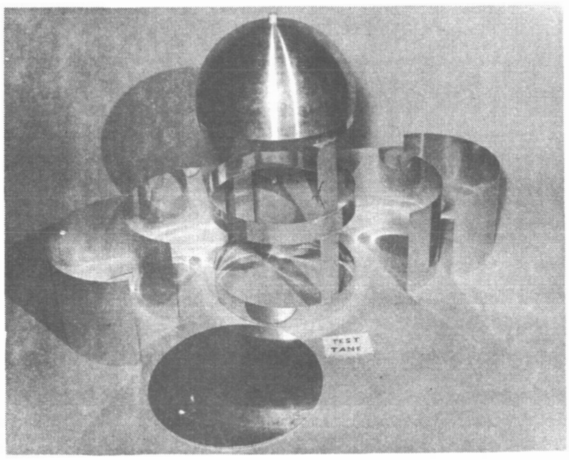
FIGURE 5 - TYPICAL GLUEWELD JOINT



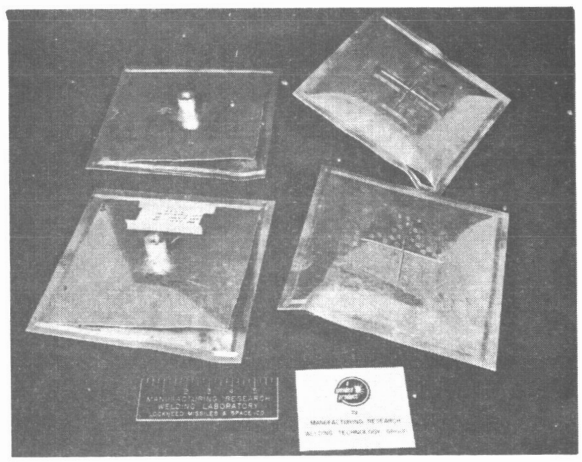
Components of Low-Cost
20-In. Tank Model



20-In. -Dia. Tank
Test Configuration



Tank Components Subassembled
Prior to Adhesive and
Resistance Joining
(Glue-Weld)



Pillow Test Tanks Employing Glue-Weld
Cruciform Joint; Deliberate
Burst Failure

Fig. 6 Low-Cost Tank Development, Demonstrating
Glue-Weld (Spot-Bond) Joints

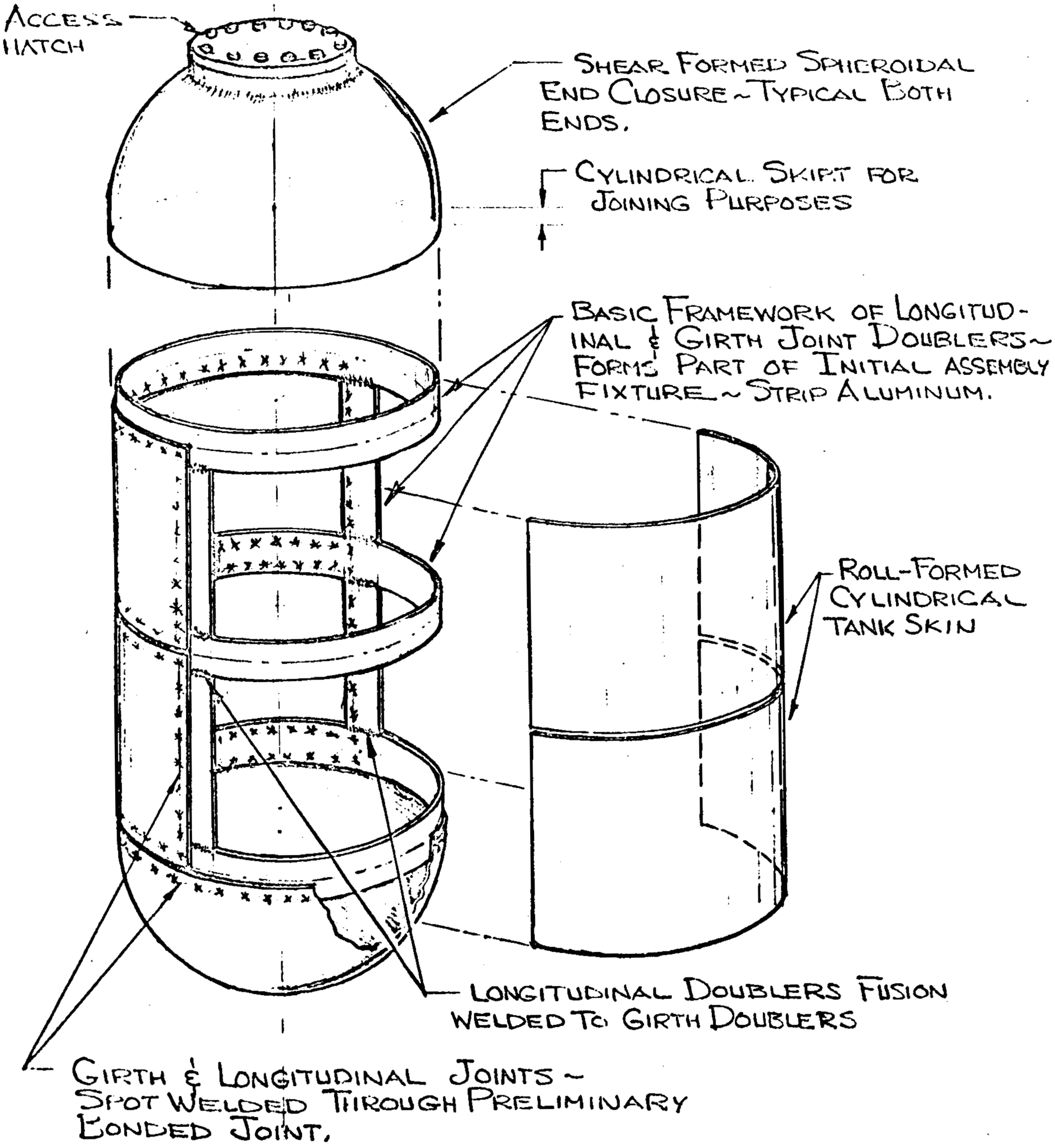
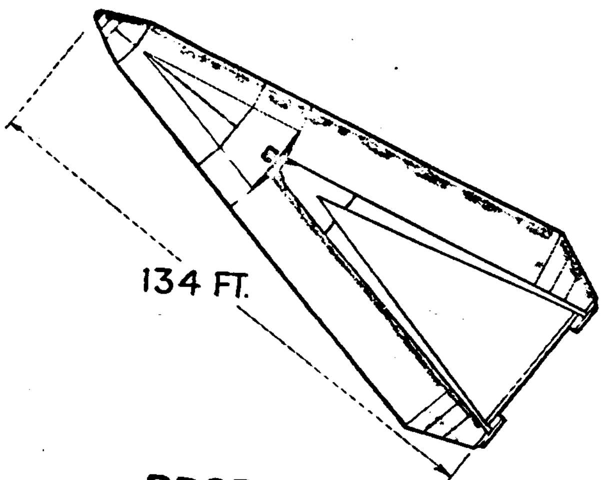
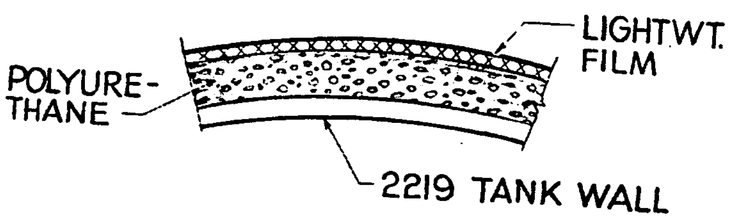


Fig. 7 Application of Glue-Bond/Resistance-Weld Joining Technique to Subscale Tank Specimen

DROP TANK FABRICATION & COST



DROP TANK FABRICATION



TYP. SECTION LH_2 TANK

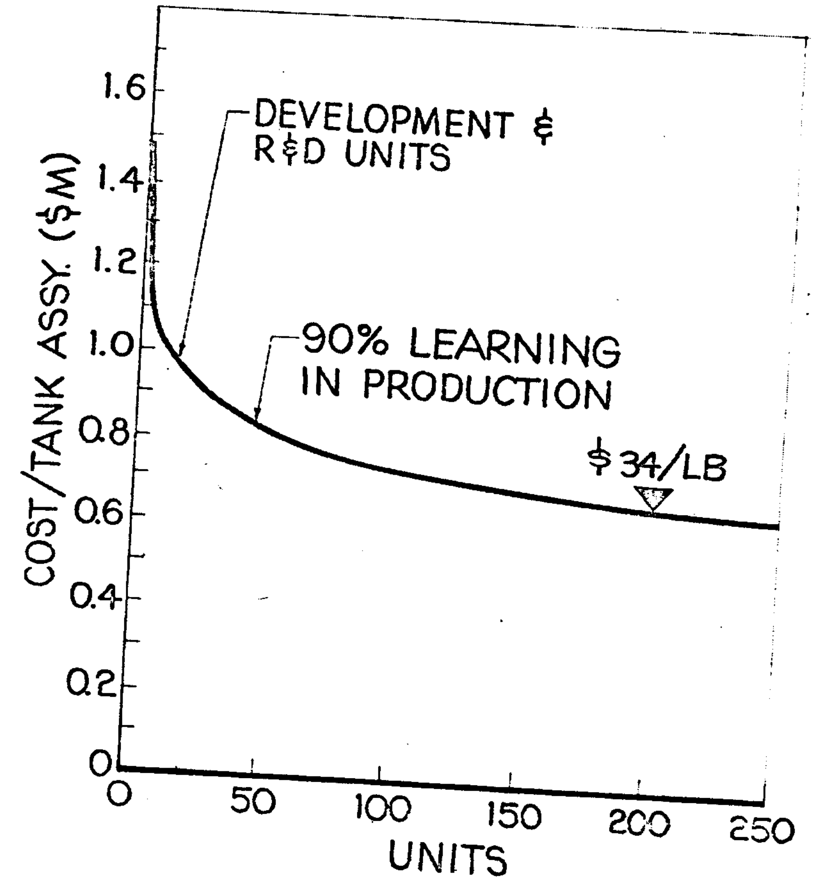


FIGURE 8

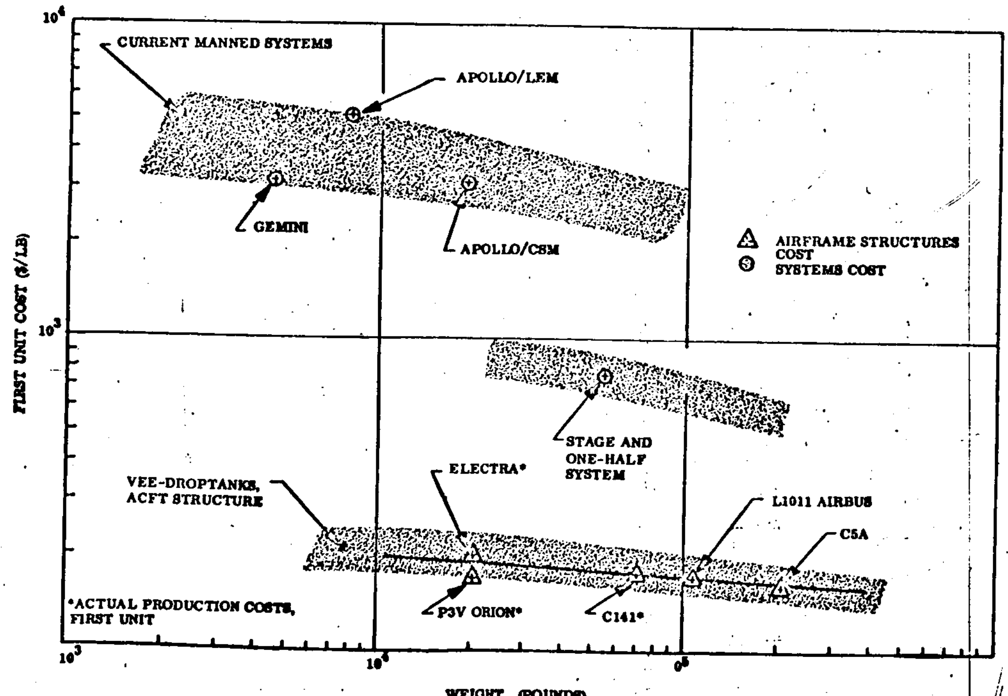


Fig. 9 Cost per Pound Versus Weight – First Production Unit

TABLE I
MATERIAL CHARACTERISTICS

Property / Material	Condition	Test Temp. (°F)	Forming Capability *	Machining Capability *	Weldability *	Availability *	Temperature Service Range °F **	Sheet Cost ($/lb)
Aluminum 2219	-T87	RT -320 -423	E	E	G	Mill order only	-423/300	1.00
2021	-T81	RT -320 -423	E	E	G	Mill order only	-423/300	1.08
6061	-T62	RT -320 -423	E	E	E	Stock	-423/300	2.08
5083	-H39	RT -320 -423	E	E	E	Stock	-423/300	2.02
7039	-T6	RT -320 -423	E	E	F-G	Mill order only	-423/300	2.50
Stainless Steel 301	3/4 H 40% Red.	RT -320 -423	G-E	F-G	G	Stock	-423/1600	1.85
310	3/4 H 40% Red.	RT -320 -423	G-E	F-G	G	Stock	-423/1600	2.21
AM 355	CR & Temp.	RT -320 -423	G-E	G	G	Stock	-423/1600	2.86
17-7 PH	TH1050	RT -320 -423	G	G	G	Stock	-423/1600	2.33
Titanium Unalloyed	Annealed	RT -320 -423	F-G	F	G	Stock	-423/1200	11.00
5Al-2.5 SN ELI	Annealed	RT -320 -423	F-G	F	G	Stock	-423/1200	11.00
6Al-4V ELI	Annealed	RT -320 -423	F-G	F	G	Stock	-423/1200	11.00
Steel HY-140		RT -320 -423	G	G	G	Mill order only	-100/1000	2.00
18% Ni Managing (250)	S. T. & Aged	RT -320 -423	G	G	G-E	Stock	-423/1200	2.50
Nickel Base Rene' 41	S. T. & Aged	RT -320 -423	F-G	F-G	G	Stock	-423/1650	9.18
Inconel 718	Annealed & Aged	RT -320 -423	F-G	F-G	G	Stock	-423/1650	3.57
			*E = Excellent G = Good F = Fair, but no real problems			"Stock" may be 2-12 weeks delivery.	** Upper end of range for 300 seconds duration, maximum	

BELLCOMM, INC.

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